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ORIGINAL PAPER

Allometry, above-ground biomass and nutrient distribution in *Ceriops decandra* (Griffith) Ding Hou dominated forest types of the Sundarbans mangrove forest, Bangladesh

Mahmood Hossain · Mohammad Raqibul Hasan Siddique · Arun Bose · Sharif Hasan Limon · Md. Rezaul Karim Chowdhury · Sanjoy Saha

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Abstract The Sundarbans, the world's largest single expanse of natural mangroves located in southern Bangladesh, is the most productive mangrove ecosystem in the world. *Ceriops decandra* (Griff.) Ding Hou is the dominant shrub in the strong saline zone of the Sundarbans and is mainly extracted for fuel wood, charcoal and tannin. The harvest of *C. decandra* has decreased by about 50 % in the Sundarbans during the last 10 years creating a major concern. This study derived allometric models of above-ground biomass and estimated of above-ground standing and harvestable biomass and nutrient stock in *C. decandra* in dominant forest types (*C. decandra* and *C. decandra*–*Excoecaria agallocha*) in the Sundarbans. Allometric relationships between collar girth (CG) and biomass of plant parts (leaf, branch and stem) were tested using linear, power and logarithmic equations. The power equation was found to be most suitable. The density and the estimated total aboveground biomass of *C. decandra* in *C. decandra* and *C. decandra*–*E. agallocha* forest types were 33,237 and 965 stems/ha (density) and 33.49 and 14.36 t/ha (biomass), respectively. Also, 13.56 and 6.61 t/ha of harvestable biomass were estimated, from *C. decandra* and *C. decandra–E. agallocha* forest types, respectively. Nitrogen, potassium and phosphorus concentrations in the leaves, branches and stems showed significant ($p < 0.05$) variation. The findings of the present study will help to quantify the impact of present harvesting techniques and alteration of different silvicultural intervention like fixation of felling cycle, felling criterion, and regeneration and slash treatment.

Keywords Allometry · Biomass · *Ceriops decandra* · Mangroves · Nutrients · Sundarbans

M. Hossain (✉) · M. R. H. Siddique · A. Bose · S. H. Limon · Md. R. K. Chowdhury · S. Saha
Forestry and Wood Technology Discipline, Khulna University, Khulna 9208, Bangladesh
e-mail: mahmoodhossain@hotmail.com

M. R. H. Siddique
e-mail: raqibulhasan_fwt@yahoo.com

A. Bose
e-mail: arun.bose2@gmail.com

S. H. Limon
e-mail: hasanlimon2000@yahoo.com

Md. R. K. Chowdhury
e-mail: rezaulkarim91@hotmail.com

S. Saha
e-mail: sanjoyfwt@yahoo.com

Introduction

Mangroves are important productive ecosystems both ecologically and economically, and provide numerous goods and services to the coastal communities (Giri et al. 2010). This ecosystem is the source of a variety of wood and non-wood forest products which include timber, fuel wood, charcoal, pulp, fodder, thatch, honey, wax

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and medicine (Field 1995; FAO 2003). Several commercially important fish, shellfish species and marine animals use this ecosystem as feeding, breeding and nursery grounds (Matthes and Kapetsky 1988). Net primary productivity of mangroves is believed to be greater than that of terrestrial tropical forest (Komiyama et al. 2008). However, this unique ecosystem is becoming degraded at an alarming rate because of the conversion of forest land and unsustainable exploitation of its resources (FAO 2003; Khan et al. 2005; Giri et al. 2008). Standing biomass and biomass increment of woody plant species are widely used indicators of primary productivity, harvestable amount of wood and degradation status of wood resources. Also, standing biomass is used to assess the cycling of organic matter and nutrient, carbon sequestration, structural development and stress level (Copper 1983; Soares 1997; Specht and West 2003; Lovelock et al. 2005). Biomass of a forest can be measured using both the destructive and non-destructive techniques (Cintron and Schaeffer-Novelli 1984). Allometric technique of biomass estimation is a non-destructive, species and site specific method (Khan et al. 2005; Chave et al. 2005; Soares and Schaeffer-Novelli 2005; Smith and Whelan 2006; Kairo et al. 2009). Allometric biomass models [$B = f(V_1, V_2)$] are designed to relate biomass (B) to quantities (V_i), which is an easy and nondestructive method of measuring a tree's dimensions such as diameter and height (Ketterings et al. 2001; Mahmood et al. 2008).

The genus *Ceriops* is represented by only two species in the Asia and Pacific regions. *Ceriops decandra* is a slow growing species which dominates the strongly saline zone (>15 ppt) of the Sundarbans of Bangladesh (Siddiqi 2001). Stem are harvested at a height of 1.5 m with a collar girth of more than 7.9 cm with a 20 year rotation and at least one stem is left for each clump (Biswas and Choudhury 2007). *Ceriops decandra* is commercially harvested for fuel wood, charcoal and tannin and has become an important commercial species of the Sundarbans and source of a considerable amount of revenue (0.2 million US dollars/yr) (Helalsiddiqui 1999). The average annual extraction rate for this species from the Sundarbans was about 50,000 M tons/year during 1990–2000 but this amount has been drastically reduced during the recent years. There is distinct evidence of uncontrolled felling and over exploitation of *C. decandra* from the Sundarbans (Iftekhar and Islam 2004). Over exploitation may increase the biomass harvest initially, but the production may not be sustainable. Sustainable production depends on the relationship between silvicultural interventions and nutrient demand (Johnson et al. 1982; Johnson and Todd 1998). Nutrient removal by harvest and its potential consequences on future nutrient cycling and productivity of a forest have been well documented (White 1974; Hansen and Baker 1979; Morrison and Foster 1979; Tritton et al. 1987; Federer et al. 1989; Hornbeck et al. 1990). Information on biomass stocking and nutrient distribution in both above and below-ground parts of trees are essential for assessing sustainable production and as well as evaluating the impact of various silvicultural practices (Santa Regina 2000). The present study is designed to derive allometric models of above-ground biomass, estimate standing above-ground and harvestable biomass and nutrients stock in *C. decandra* from its dominant forest types (*C. decandra* and *C. decandra*–*E. agallocha*) of the Sundarbans.

Methods

Study area

This study was conducted at *C. decandra* dominated sites (*C. decandra* and *C. decandra*–*E. agallocha* forest types) of the Sundarbans mangrove forest, Bangladesh, between latitudes of 21°41′ and 21°56′ N and longitudes of 89°06′ and 89°16′ E. Dwarf *E. agallocha* is the main species over dense *C. decandra*, interspaced with dense patches of *Phoenix paludosa* on the drier soils. *Xylocarpus granatum, X. mekongensis* and *Bruguiera sexangula* occur sporadically throughout the study area. The subtropical climate of this area is strongly seasonal with 87 % of the mean annual rainfall (1,500 mm) occurring between May and October. Maximum and minimum temperatures range from 18.5 to 35.2 °C in summer and 12.2–28.8 °C during winter. Soil texture is a silty to sandy clay loam. Bulk density, particle density and porosity of the *C. decandra* forest type soil vary from 1.2 to 1.24 gm/cc, 2.16 to 2.38 gm/cc and 45–49 %, respectively. Also, soil bulk density, particle density and porosity of the *C. decandra*–*E. agallocha* forest type were 1.18–1.27 gm/cc, 2.31–2.52 gm/cc and 46–52 %, respectively. The mean pH, conductivity and salinity of the soil were 7.8, 1.19 mS/cm and 5.94 dS/cm, respectively. Organic carbon (C), available nitrogen (N), phosphorus (P) and potassium (K) in soil of the *C. decandra* forest type were

Table 1 Sampled stems along with their collar girth and oven-dried biomass of their different parts

Collar girth (cm)	Leaf biomass (g)	Branch biomass (g)	Stem with bark biomass (g)	Bark biomass (g)	Total above ground biomass (g)
6.91	172.79	132.60	366.00	81.30	671.39
11.62	390.59	367.20	561.20	124.66	1318.99
5.65	71.15	40.80	170.80	37.94	282.75
3.77	27.59	15.30	48.80	12.00	91.69
8.16	183.68	234.60	427.00	94.85	845.28
10.36	368.81	377.40	634.40	140.92	1380.61
3.93	49.37	15.30	54.90	12.20	119.57
3.77	34.85	10.20	57.95	12.87	103.00
3.77	34.85	10.20	48.80	10.84	93.85
6.28	85.67	45.90	195.20	43.36	326.77
7.69	259.91	239.70	427.00	94.85	926.61
6.28	151.01	142.80	353.80	78.59	647.61
6.91	147.38	91.80	262.30	58.27	501.48
11.62	535.79	765.00	805.20	178.86	2105.99
7.22	100.19	91.80	366.00	81.30	557.99
7.85	256.28	204.00	488.00	108.40	948.28
9.89	288.95	214.20	671.00	149.05	1174.15
11.93	180.05	153.00	719.80	159.89	1052.85
16.64	586.61	1142.40	2098.40	466.12	3827.41
16.33	767.00	1468.80	1671.40	371.27	3907.20
12.87	710.03	918.00	835.70	185.64	2463.73
15.07	942.35	1315.80	1488.40	330.62	3746.55
19.15	1269.05	2896.80	2501.00	555.55	6666.85
18.84	1341.65	2295.00	2623.00	582.65	6259.65
14.13	535.79	765.00	1647.00	365.85	2947.79
12.25	339.77	989.40	1220.00	271.00	2549.17
12.56	637.43	989.40	1342.00	298.10	2968.83
13.19	506.75	1071.00	1159.00	257.45	2736.75
16.64	978.65	1683.00	1830.00	406.50	4491.65
12.56	506.75	673.20	1171.20	260.16	2351.15
12.56	499.49	775.20	1159.00	257.45	2433.69
17.27	906.05	1530.00	2342.00	485.73	4778.05
12.00	450.12	408.00	756.40	163.06	1614.52
11.00	413.82	428.40	732.00	157.8	1574.22
12.00	689.70	1020.00	1122.40	241.96	2832.10
11.00	217.80	408.00	744.20	160.43	1370.00
10.80	258.96	327.80	531.05	110.14	1117.82
9.60	99.60	163.90	493.12	102.27	756.62
8.80	179.28	102.44	404.61	83.91	686.33
10.50	132.80	163.90	480.47	99.65	777.18
9.20	185.92	143.42	505.76	104.89	835.10
18.20	567.00	1249.77	2554.09	529.70	4370.86
23.70	1233.00	2989.00	3477.10	721.12	7699.10
21.80	987.00	2345.00	3344.00	693.55	6676.00

Table 1 continued

Collar girth (cm)	Leaf biomass (g)	Branch biomass (g)	Stem with bark biomass (g)	Bark biomass (g)	Total above ground biomass (g)
22.60	897.00	3091.00	3245.00	673.01	7233.00
20.10	776.00	2455.00	3011.00	624.48	6242.00
27.40	1567.00	4978.00	5543.00	1149.62	12088.00
23.80	1023.00	4677.00	3793.20	786.68	9493.20

2.24 ± 0.03 %, 1.59 ± 0.13 mg/g, 4.27 ± 0.16 mg/g and 1.89 ± 0.10 mg/g, respectively. However, 2.27 ± 0.02 %, 1.31 ± 0.15 mg/g, 4.17 ± 0.15 mg/g and 1.83 ± 0.07 mg/g of organic C, available N, P and K were observed in soil of *C. decandra*–*E. agallocha* forest type, respectively.

Allometric model

Forty-eight (48) individual stems of *C. decandra* having a girth >3 cm at the collar region were selected from both the *C. decandra* and *C. decandra*–*E. agallocha* forest types as samples (Table 1). Only healthy and visibly undamaged stems were selected and the girth at root collar region was measured for each stem. The stems were then separated into different parts (leaves, branches, and stem) and weighed in the field. Fifteen randomly selected stems were debarked in the field to get the ratio of green weight of bark and stem. Green weight of bark of an individual stem was calculated from the mean ratio of bark and stem weight. Subsamples of leaves, branches, barks and stems were brought back to the laboratory and oven-dried at 80 °C to estimate green weight using oven-dry weight conversion factors. Oven-dry weights of plant parts were calculated from the conversion factors and green weight of the respective plant parts. Different regression equations (simple linear, power and logarithmic) were tried to get the best fitted allometric models for estimating the oven-dried biomass of plant parts. A significance test of the regression equations was conducted by using SAS (6.12) statistical software. The selection of best fitted allometric models was conducted by considering the parameter of estimates such as R^2, CV, MS_{error} and P value.

Above-ground biomass

One hundred random sample plots (10 m × 10 m) were established in each of the *C. decandra* and

Table 2 Parameter of estimates of allometric equations

Plant parts	Equation	R^2	b	a	CV	MS_{error}	Sa	F value
Leaf	$y = ax + b$	0.84	−286.93	62.59	32.60	25570.39	4.05	238.75
	$y = ax^b$	0.89	2.99	1.95	6.06	0.02	0.10	367.71
	$y = a\ln(x) + b$	0.74	−1132.42	674.70	41.34	41112.00	58.93	131.10
Branch	$y = ax + b$	0.85	−1369.83	188.48	48.28	219858.12	11.88	351.77
	$y = ax^b$	0.94	0.23	3.09	6.65	0.03	0.12	717.30
	$y = a\ln(x) + b$	0.64	−3540.46	1875.61	74.09	517692.47	209.01	80.46
Bark	$y = ax + b$	0.93	−251.55	42.02	24.89	4527.88	1.70	607.60
	$y = ax^b$	0.97	0.77	2.23	4.09	0.01	0.06	3165.02
	$y = a\ln(x) + b$	0.34	−2466.32	1256.79	159.32	786860.56	257.79	23.77
Stem with bark	$y = ax + b$	0.92	−1233.31	200.75	26.71	113257.68	8.53	554.45
	$y = ax^b$	0.97	3.22	2.27	3.06	0.01	0.06	1488.74
	$y = a\ln(x) + b$	0.73	−3673.28	2050.52	49.95	396106.88	182.90	125.69
Total above ground	$y = ax + b$	0.92	−2890.06	451.83	29.51	645143.36	20.35	493.06
	$y = ax^b$	0.97	4.70	2.41	3.16	0.01	0.07	1278.93
	$y = a\ln(x) + b$	0.72	−8345.17	4600.83	53.39	2111684.40	422.31	118.69

S_a is standard error of regression coefficient ''a''

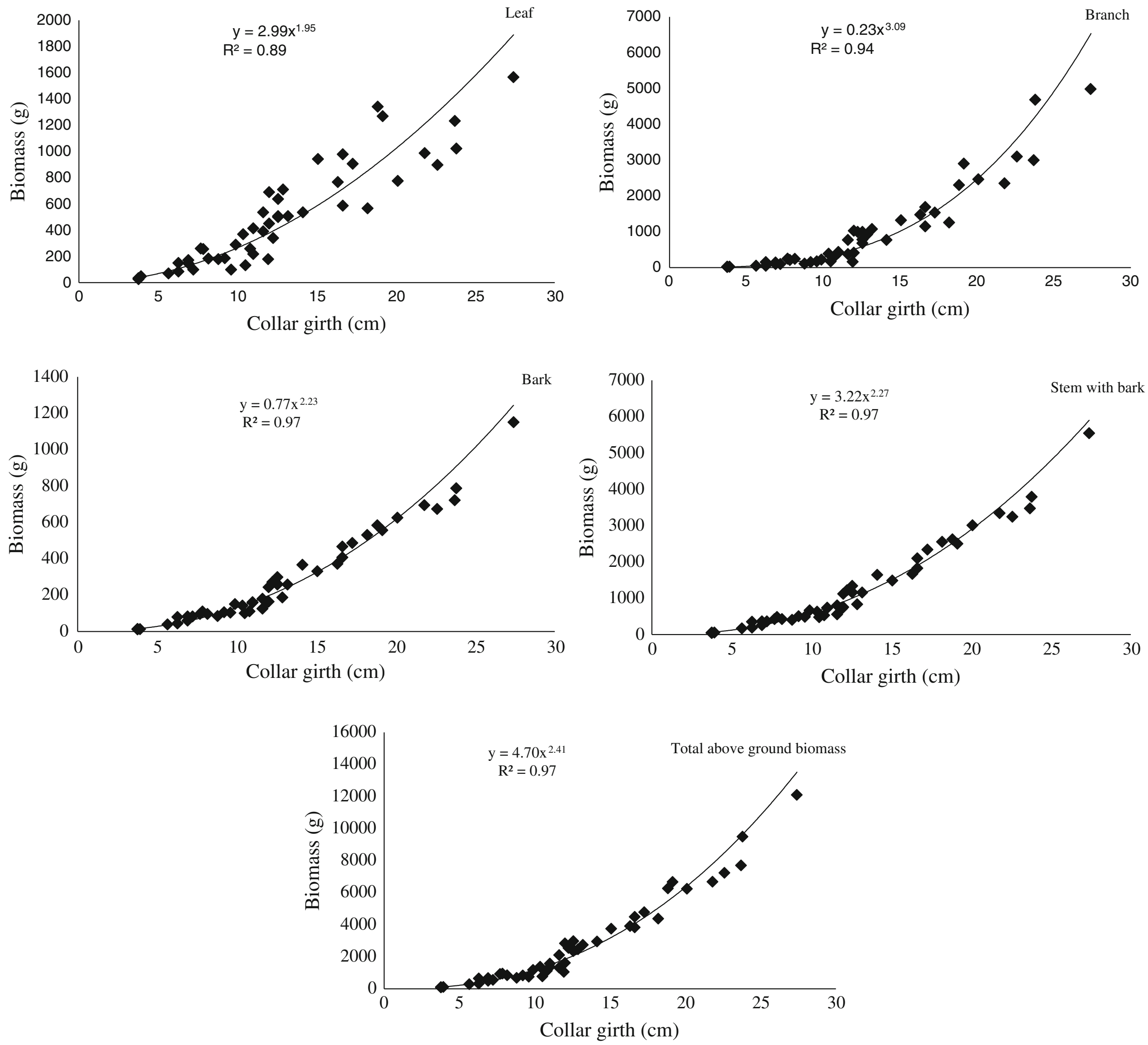

Fig. 1 Allometric relationship between collar girth and oven-dry biomass of different parts of *Ceriops decandra*

C. decandra–E. agallocha forest types. All individual *C. decandra* stems within the sample plots were counted and their collar girths were also recorded. Density of *C. decandra* in each forest type was calculated from the relationship given by Cintron and Schaeffer-Novelli (1984). Above-ground biomass of different parts of *C. decandra* was estimated from the derived allometric equations, mid value of each collar girth class and stem density of the respective classes. Here, harvestable biomass was estimated from the density of stem having a collar girth higher than 7.9 cm. Finally, these biomass values are expressed in t/ha.

Nutrients in plant parts

The sub-samples of leaves, branches, barks and stems were processed and acid digested based on Allen (1974). N and P concentration in sample extracts were measured based on Weatherburm (1967) and Timothy et al. (1984), respectively, using a UV–Visible Spectrophotometer (Hitachi U-2910: 2J1-0012, Japan). K in sample extracts was measured with a Flame Photometer (Jenway PFP7, England). Nutrient (N, P, and K) stock in plant biomass was calculated by multiplying the oven-dried biomass of plant parts with the concentration of respective nutrients. Nutrient (N, P and K) concentration in plant parts at

Table 3 Collar girth class, density and biomass proportion in different parts of *Ceriops decandra*

Collar girth class (cm)	Density (stem/ha) of forest type		Pant parts (%)		
	Ceriops decandra	*C. decandra–Excoecaria agallocha*	Leaves	Branches	Stem
1.00–3.00	122	83	38.75	5.67	55.58
3.01–6.00	7,330	717	31.91	14.76	53.33
6.01–9.00	13,332	2,600	27.90	22.04	50.06
9.01–12.00	8,095	3,917	24.97	28.08	46.95
12.01–15.00	2,882	1,533	22.68	33.17	44.15
15.01–18.00	1,069	483	20.80	37.56	41.64
18.01–21.00	242	217	19.23	41.38	39.39
21.01–24.00	165	100	17.89	44.72	37.39

different sites were compared by one way analysis of variance (ANOVA) followed by List Significant Difference (LSD) by using SAS (6.12) statistical software.

Results

Allometric model

The range of collar girth of the sampled stems of *C. decandra* was 3.77–27.4 cm; Table 1 presents the oven-dried biomass of different parts of stems. Oven dried weights of plant parts were plotted against the collar girth (CG) on linear, power and logarithmic regression equations. All the equations were significant ($p < 0.05$) and the power equations showed comparatively higher R^2 and F value together with lower CV and MS error than linear and logarithmic equations. The regression equations used for estimating above-ground biomass of different parts of *C. decandra* were $y = 2.99x^{1.95}$ for leaves, $y = 0.23x^{3.09}$ for branches, $y = 0.77x^{2.23}$ for bark, $y = 3.22x^{2.27}$ for stem with bark and $y = 4.70x^{2.41}$ for total above ground biomass (Table 2; Fig. 1).

Above-ground biomass

The density of *C. decandra* in *C. decandra* and *C. decandra–E. agallocha* forest types were 33,237 and 965 stems/ha respectively. Comparatively higher density (13,332 stems/ha) was observed for 6.01–9.00 cm girth class (CG) class in *C. decandra* forest type. Higher density (3,917 stems/ha) was recorded for 9.01–12.00 cm CG class in *C. decandra–E. agallocha* forest types. The biomass proportion of plant parts varied with CG classes. The plants having lower GC (1.00–3.00) had higher proportion of leaf and lower proportion of branch while the plants with higher GC (21.00–24.00) had lower proportion of leaf and higher proportion of branch biomass. On average stems accounted for 46 % of biomass, branches for 28 % and leaves for 26 % (Table 3). The estimated total above-ground biomass of *C. decandra* was 33.49 and 14.36 t/ha in *C. decandra* and *C. decandra–E. agallocha* forest types, respectively. Also, 13.56 and 6.61 t/ha of harvestable biomass were estimated, from *C. decandra* and *C. decandra–E. agallocha* forest types, respectively (Table 4).

Nutrients in plant parts

Nutrient (N, P and K) concentration significantly (ANOVA, $p < 0.05$) varied among the plant parts. Comparatively higher concentrations of nutrients were observed in leaves followed by branches and the lowest content was detected in stems (Table 5). Also, there was no significant (ANOVA, $p < 0.05$) differences in nutrient concentrations of leaves, branches,

Table 4 Above-ground and harvestable biomass (t/ha) of *Ceriops decandra* in different forest types

Forest type	Above-ground biomass (t/ha)				Harvestable biomass (t/ha)
	Leaf	Branch	Stem	Total	
C. decandra	7.38	9.13	16.98	33.49	13.56
C. decandra–E. agallocha	2.98	4.23	7.15	14.36	6.61

Table 5 Nutrients concentration (mg/g) in different parts of *Ceriops decandra*

Plant components	Nutrient concentration (mg/g)		
	Nitrogen	Phosphorus	Potassium
Leaf	16.1 ± 0.48	0.17 ± 0.01	4.91 ± 0.15
Branch	10.83 ± 0.73	0.11 ± 0.01	3.13 ± 0.16
Bark	9.46 ± 0.42	0.05 ± 0.01	2.43 ± 0.12
Stem	8.66 ± 0.42	0.07 ± 0.01	1.82 ± 0.09

bark and stems of *C. decandra* in two different forest types. Higher amounts of N were present in above-ground biomass of *C. decandra* followed by P and K. The stocks of N, P and K in the *C. decandra* forest type were 364.74, 3.45, 95.72, respectively. 155.71, 1.47 and 40.88 kg/ha of N, P and K were present in the *C. decandra–E. agallocha* forest type. Also, about 35 % of N, 30 % of P and 28 % of K were present in harvestable biomass (Table 6).

Discussion

The average height of *C. decandra* stems in the Sundarbans is around 2 m and the collar girth measurement is used as a selection criterion during harvest of the plants (Biswas and Choudhury 2007). Also, using DBH as a selection criterion for *C. decandra* in the Sundarbans is impractical considering its growth form (Siddiqi 2001). So, collar girth was used as a predictive biometric variable for estimating above-ground biomass. Most authors have generally used breast height diameter (DBH), girth at breast height (GBH) and height (H) as predictive variables to estimate the above-ground biomass of mangroves by using different allometric equations (Ong et al. 1984; Putz and Chan 1986; Clough and Scott 1989; Gong and Ong 1990; Ong et al. 2004). The selection of the best regression equations is the key to allometric modeling of biomass estimation (Steinke et al. 1995; Tam et al. 1995). The power regression equation was found to be the best allometric model for biomass estimation of different parts of *C. decandra* (Table 2; Fig. 1). This power equation provides a linear relationship when oven-dry weight of plant parts and collar girth (CG) are transformed to a logarithmic function to reduce the variance for the total data and modify the non-linear line to a straight line through the least squares method (Sprugel 1983; Zar 1996). The most commonly used allometric models are polynomials and power models or a combination of the two. The shape of polynomials may be biologically unreasonable but a power model is widely used in estimating tree biomass (Causton and Venus 1981). The power curve describes the reliable relationship between above-ground biomass and diameter at breast height (DBH) or girth of trees in a terrestrial forest (Ketterings et al. 2001) and also in different mangrove species such as *Rhizophora apiculata* and *Bruguiera parviflora* at the Matang Mangrove Reserve, Malaysia (Ong et al. 1984; Gong and Ong 1990), *R. apiculata* at Palau Kecil, Malaysia (Putz and Chan 1986), *Bruguiera gymnorrhiza*, *B. parviflora*, *Ceriops tagal*, *R. apiculata* and *Xylocarpus granatum* in Northern Australia (Clough and Scott 1989) and *B. parviflora* at Kuala Selangor, Malaysia (Mahmood et al. 2004), *R. mucronata*, *Avicennia marina*, *Sonneratia alba*, *C. tagal* at Gazi Bay Kenya (Kairo et al. 2009), and for the multi-stemmed mangrove species, *R. stylosa* in northwestern Australia (Clough et al. 1997). Allometry of *C. decandra* could not be traced elsewhere. But, allometric

Table 6 Nutrient stock in above-ground and harvestable biomass of *Ceriops decandra* in different forest types

Forest types	Plant components	Nutrient (Kg/ha) in standing biomass			Nutrient (Kg/ha) in harvestable biomass		
		N	P	K	N	P	K
C. decandra	Leaves	118.82	1.25	36.24	–	–	–
	Branches	98.88	1.00	28.58	–	–	–
	Stems	147.05	1.19	30.90	117.43	0.95	24.68
	Total	364.74	3.45	95.72			
C. decandra–E. agallocha	Leaves	47.98	0.51	14.63	–	–	–
	Branches	45.81	0.47	13.24	–	–	–
	Stems	61.92	0.50	13.01	57.24	0.46	12.03
	Total	155.71	1.47	40.88			

models for *C. tagal* were tried by Clough and Scott (1989) and Kairo et al. (2009). Kairo et al. (2009) considered stem diameter at one half of the tree height and could not find a significant model for it whereas Clough and Scott (1989) found significant models using DBH. None of these methods is applicable for comparison of this study.

Biomass proportion of plant parts varied with the collar girth classes of *C. decandra* (Table 3). A similar trend was also observed for *B. parviflora* in Malaysia (Mahmood et al. 2004). Plant size and age have significant influence on partitioning of above-ground biomass into various pant parts (Clough et al. 1997; Peichl and Arain 2007). Different mangrove species showed different proportions of biomass allocation to various parts. The biomass proportion in different parts of mangrove species depends on species specific architecture at different stages (seedlings, saplings and trees), plant form, stand structure, regional climate and environmental factors (Steinke et al. 1995; Tam et al. 1995; Clough et al. 1997; Mahmood et al. 2004). The variation in density of *C. decandra* in *C. decandra* and *C. decandra–E. agallocha* forest types could be responsible for the different values obtained for above-ground and harvestable biomass. Mangrove plants at different places showed a wide range of biomass from 6.80 t/ha (Woodroffe 1985) to 460 t/ha (Putz and Chan 1986). Unlike other forest ecosystem, biomass production in mangroves is influenced by a variety of factors such as geographical location, forest types, stand structure, management intervention, biomass partitioning along with other abiotic factors (Saenger and Snedaker 1993; Tam et al. 1995).

Comparatively higher concentrations of nutrients were observed in leaves and lower levels were found in stems (Table 5). In the present study, the trend of N, P and K concentrations in different parts of *C. decandra* similar to that of *R. apiculata* (Ong et al. 1984), *Avicennia* spp. *Bruguiera* spp. and *Ceriops* spp (Aksornkoae and Khemnark 1984) and *B. parviflora* (Mahmood et al. 2003). Leaves and green parts of plants contain higher amounts of nutrients than woody parts such as stems and branches (Binkley 1986). The plant species, physiological age of the tissue, position of the tissue in the plant, available forms of nutrients in substrate, concentrations of other nutrients, climatic and soil edaphic factors affect the extent of nutrient variation in plant parts (Mahmood et al. 2003). Also, different mangrove species might have different rates of nutrient uptake and distributional patterns in their parts which may have also been site and species specific (Alongi et al. 2005; Mahmood 2007; Krishtensen et al. 2008; Mahmood et al. 2008). The variation of nutrients in above-ground and harvestable biomass from two different forest types of *C. decandra* could be caused by the variation in density and biomass. Nutrient distribution patterns in plant parts and nutrient stock in biomass have great importance in predicting nutrient export under different forest management techniques like thinning, pruning and harvesting (Augusto et al. 2000). Only the stem section of *C. decandra* is harvested from the Sundarbans; leaves and branches are left behind on the forest floor which contributes to nutrient cycling in this ecosystem. However, nutrient export through harvesting from any forest is an important consideration for short rotation species, and excess amounts of nutrient export has an adverse impact on long term site quality and production (Hopman et al. 1993; Swamy et al. 2004). The relationship between forest production and nutrient availability are not sufficiently known and has become a critical issue in sustainable forest management (Ong et al. 2004; Kairo et al. 2009). However, a comprehensive knowledge on biomass and nutrient stock, harvestable amount of biomass and possible nutrient export through harvest of *C. decandra* from different forest types of the Sundarbans may have prime importance in enabling a proper evaluation of resource management. Also, the findings of the present study will help to assess the potential for temporarily sequestering atmospheric CO_2 in the Sundarbans mangrove ecosystem, and provide insight into the impact of present harvesting scheme and alteration of different silvicultural techniques such as determination of the harvest cycle, felling criteria, and regeneration and slash treatment. But, further study on productivity and nutrient cycling at the stand level is needed to evaluate the impact of silvicultural intervention on bio-element recycling and the long term effect on the mineral balance and sustainable production.

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